EFFECT OF ELECTROLYTIC CURRENTS ON A CURRENT CARRYING CONDUCTOR

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ABSTRACT. Superimposition of electrolytic current on a current carrying conductor (Pt. Wire) is studied by keeping the heating currents constant. The effect has been found to be purely a change of potential difference across the two ends of the wire dipped in an electrolyte at constant temperature. This effect is not due to the change of resistance of the wire (i.e. due to change of temperatre of the wire) but due to the point to point variation of current in the wire. The contention is supported by theoretical considerations, which are verified experimentally.

INTRODUCTION

Effect of ionic currents (electrolytic bubbles) on heat-transfer was reported by Mixon and du pont (1959) to show that there is some lowering of the heat transfer at high electrolytic currents. Arjas and Legvold (1958) have studied a similar phenomenon in gases. Edkie, Rao and Gogate (1961) have reported in a note that at first there is a gradual rise in the heat transfer and then there is a sudden fall at high ionic currents. Bhand, Gaur and Gogate (1963) and Bhand, Patgaonkar and Gogate (1963) have investigated the effect in more details and have reported continuous curves of rise and then fall of the heat transfer coefficients with increase of electrolytic currents. In the curves for h/h_0 against log i (i being electrolytic current) using the same platinum wire at different temperatures, the maximas in all the cases seem to be present at about 100 mA. electrolytic current. In the other curves for different platinum wires also the maximas will be obtained at about 100 mA. of electrolytic current if current densities (currents per equal area of the surface) were considered. Due to these peculiar results and the reported analogy to the heat transfer in boiling liquids, in the present work these effects have been studied in greater details, the effect being reported upto 400 mA.

Using similar arrangements as by Bhand, Gaur and Gogate (1963) and taking a platinum wire of 0.015 cm. diameter; 15.2 cm. length and keeping $\Delta\theta = 8.3°C$ above the temperature of bath, the effect was observed upto 1000 mA. of electrolytic current. The effect is shown in Fig. 1. h/h_0 reduces to almost zero at about 800 mA. of electrolytic current. If the electrolytic current is increased further the bridge remains unbalanced. In the observations reported by Bhand, *et al*, it is assumed that at lower electrolytic currents due to increase in the heat transfer the temperature and thus the resistance of the wire falls, which is then

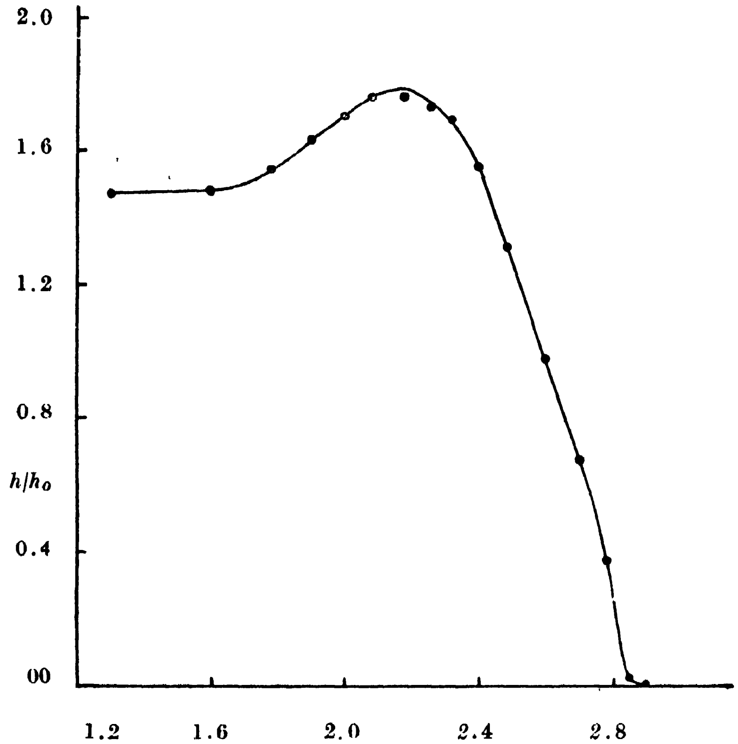

Fig. 1. Curve showing variation of h_1/h_0 against log i (i being the electrolytic current in mA)

brought back to its original value by increasing the heating current I. And that at higher electrolytic currents due to the presence of bubble formation on the platinum wire (Positive electrode) there is a blocked of heat flux and hence the temperature and thus the resistance of the platinum wire rises which is brought back to its original value again by decreasing the heating current I. In the observations (Fig. 1) the effect looks to be similar with a maxima at about 100 mA. of electrolytic current, but it is difficult to accommodate the increase in the resistance of the platinum wire to maintain its temperature at $\Delta\theta = 8.3°C$ above the bath temperature at nearly 800 mA. electrolytic current and on almost zero heating current. What kind of heat blockade could heat the wire when there is almost no heating current ? These observations thus create a suspicion in the validity of the assumptions of the so-called fall or rise of the resistance of the platinum wire. Therefore, the problem has been restudied by keeping the heating currents constant and measuring the so-called actual fall or rise in the resistance of the platinum wire with the electrolytic currents.

EXPERIMENTAL

The experimental arrangement used is shown in Fig. 2 in which AB is the platinum wire dipped horizontally in a large tube full of an weak electrolyte and is surrounded by a co-axial cylinder; the weak electrolyte was just tap water without adding any acid or alkali. The cylinder and the platinum wire form the two electrodes for the electrolytic circuit. The electrolytic current is fed

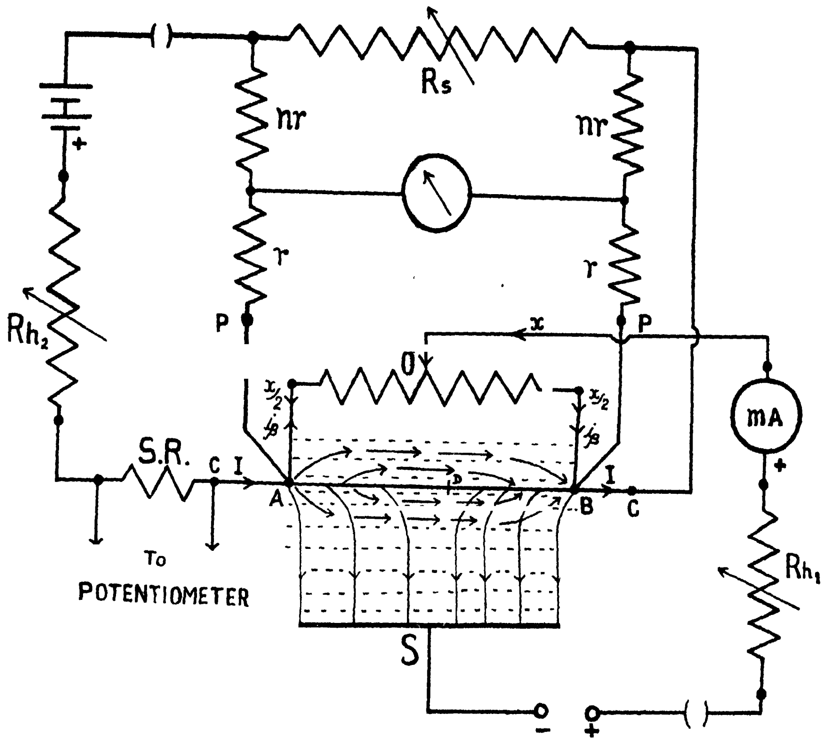

Fig. 2. Circuit diagram used for measurements. Rs is the calibrated resistance arm of the PYE *Kelvin Bridge*.

from a D.C. Generator through a certain tapping 0 of a high resistance of about 143 ohms put in parallel with the platinum wire. The D.C. Compound Generator used is G.E.C. F.2.A, which is run by a three phase A.C. motor and maintains constant voltage of 220V. upto 22.7 Amps. current. The required electrolytic current was adjusted and maintained constant with the help of a rheostat Rh_1 in series with the generator. The platinum wire forms the unknown arm of the Kelvin's double bridge (Pye). The wire is heated by a current drawn from 12 volts Exide Batteries and is maintained constant with the help of a rheostat Rh_2 in series. A standard resistance of 0.1 ohm in series measures the heating current flowing in the platinum wire by balancing the potential difference across its terminals on a crompton potentiometer. Thus, having the same experimental arrangement as used by previous workers (Bhand, Gaur and Gogate) the procedure adopted in this measurement was that the resistanc of the heat transferring platinum wire was measured by keeping the heating acurrent constant.

For each measurement, firstly, for every electrolytic current and with no heating current, a balance was obtained in the bridge (no deflection in the galvanometer) by adjusting the tapping 0 of the shunting rheostats. This ensures that half of the electrolytic current enters at A and the other half at B each flowing on equal lengths of the platinum wire, keeping A and B at the same potential. Secondly, after removing the electrolytic current, heating current was adjusted to a particular value I and resistance R was measured. Lastly, the electrolytic current was put on and keeping the heating current constant the resistance R_i was measured. Thus increase or decrease in the resistance $\pm dR = (R_i - R)$ is known, the temperature of the bath was maintained at 20°C throughout the experiment. However by the end of the experiment in any set if there was a slight rise of temperature of the bath by 0.5°C or 1°C then R was corrected to $R(1+\alpha t)$ and thus dR was suitably corrected.

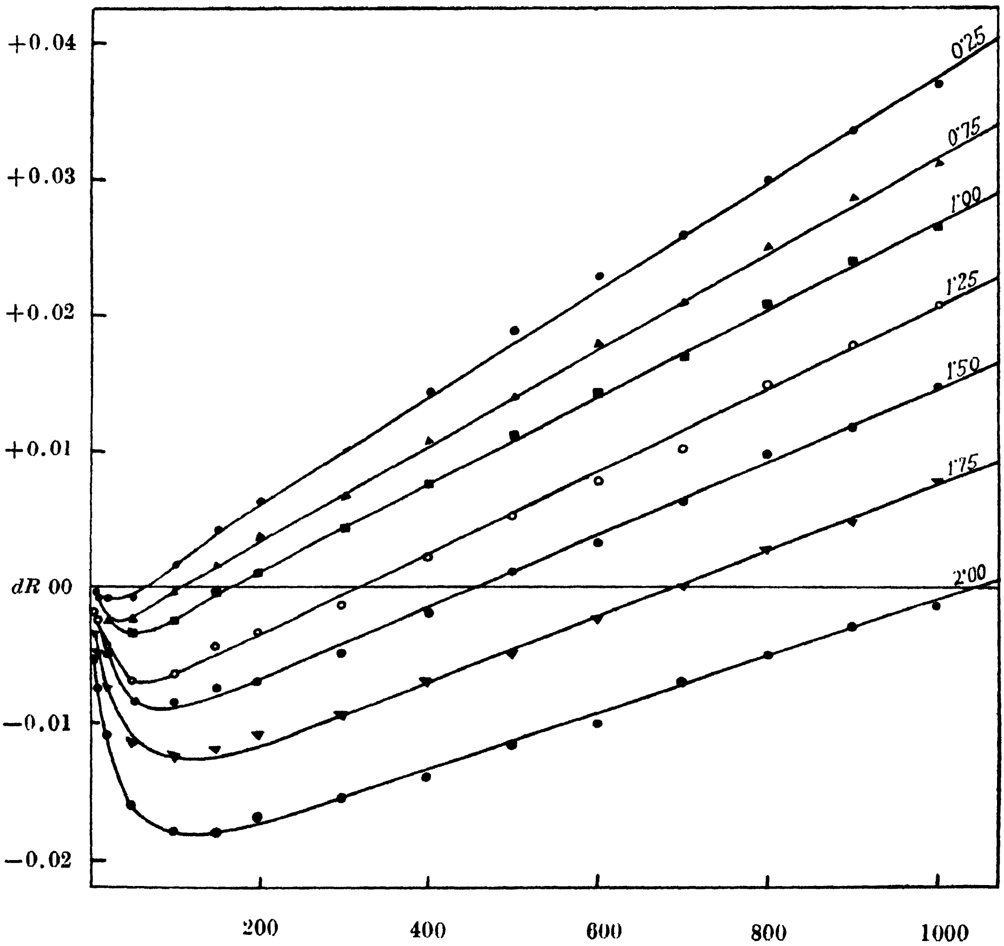

Fig. 3. Curves showing variation of dR in *ohm* with respect to electrolytic currents in *mA*. at different heating currents in amperes.

Fig. 3 shows the results obtained from these observations. The graph is a plot of dR with respect to different electrolytic currents (x) on each heating current from 0.25 amp. to 2.0 amp.

THEORETICAL CONSIDERATIONS AND INTERPRETATION OF RESULTS

From the simple considerations of the paths of heating currents I and electrolytic current x superimposed on it (see Fig. 2) it is quite clear that it is not the single current I which is flowing in the wire. Therefore, at any time to say that $(R \pm Rd)$, the measured value of the resistance from the bridge, is the resistance of the platinum wire, will not be true. It is of interest to note that I is the current entering at A and emerging at B the points at which the wire is connected to the Kelvin bridge. This is the necessary condition to obtain the balance in the bridge, that is, the bridge can be balanced if the currents in the known arm and in the leads of the unknown arm are equal. Hence it is clear that the balance of the bridge can be obtained for $(R \pm dR)$, the resistance in the known arm having a current I, when $(R \pm dR)$. I, is the potential difference across AB even when the actual current flowing in the platinum wire may be distributed or different.

In the measurement of the resistance at a current I with no electrolytic current, it is assumed that the shunting resistance is large enough and hence the branching current i_β is negligible. However, for more accurate measurements if this need be considered, let r be the real resistance of the wire and R the measured value, then as $(I - i_\beta)$ is the current flowing in the platinum wire, the potential difference across the wire AB will be

$$r(I - i_\beta) = RI$$

It may be further added that there will be some leakage of current in the electrolytic and, therefore, the whole current $(I - i_\beta)$ will not be flowing in the platinum wire and hence there will be a further decrease of potential difference across AB. Let the leakage current with no electrolytic current be also included in i_β to raise it to i'_β then we have

$$r(I - i'_\beta) = RI;$$

or

$$r = R\left(\frac{I}{I - i'_\beta}\right) = R(1+k)$$

where $k = i'_\beta / I$ nearly constant for all values of I. Therefore a correction factor of $(I+k)$ will have to be applied to all the values of R for the determination of r.

To evaluate the potential difference across the platinum wire a point to point current will have to be considered in the wire due to superimposition of the electrolytic current on $(I - i'_\beta)$ current in place of current I. Let x be the electrolytic current, then $x/2$ will be the current entering at A and $x/2$ at B. Because the potential of the A side of the wire will be higher than the potential of the B side due to the heating current it is evident that the A side length l_1 along which half the electrolytic current $x/2$ flows varying from $x/2$ to 0 will be greater than the

B side length l_2 where it varies again from $x/2$ to 0 from the end B. Thus there is a point to point variation of the current from $\left(I-i'_\beta+\frac{x}{2}\right)$ to $\left(I-i'_\beta-\frac{x}{2}\right)$.

Therefore the total potential difference across AB due to this effect

$$=\sum_0^{l_1}\sum_{x/2}^{0} dl\rho i+\sum_0^{l_2}\sum_0^{-x/2} dl\rho i \left[\begin{array}{l} i = \text{current at any point on the wire} \\ \rho = \text{resistance per unit length of the wire}\end{array}\right]$$

$$=\sum_0^{l_1}\sum_{i'=x/2}^{i'=0} dl\rho(I-i'_\beta+i')+\sum_0^{l_2}\sum_{i'=0}^{i'=x/2} dl\rho(I-i'_\beta+i')$$

i' = the effective electrolytic current at any point in the wire]

$$=l_1\rho(I-i'_\beta)+\frac{l_1\rho}{2}\cdot\frac{x}{2}+l_2\rho(I-i'_\beta)-\frac{l_2\rho}{2}\cdot\frac{x}{2}$$

$$=(l_1+l_2)\rho(I-i'\beta)+\frac{l_1-l_2}{2}.\rho.\frac{x}{2}$$

$$=\gamma(I-i'\rho)+\frac{l_1-l_2}{2}\rho\frac{x}{2}$$

$$=RI+\frac{l_1-l_2}{2}\rho\frac{x}{2}$$

In addition there will be a decrease of potential on application of electrolytic current due to increase in the leakage of the heating current through the electrolyte. Let it be a factor C, a function of heating current I and resistance of the wire. The factor C will increase with the increase of x due to increase in the conductivity and may become almost constant after attaining a maximum value at some value of the electrolytic current.

The overall potential difference across AB is

$$RI+\frac{l_1-l_2}{2}\rho\frac{x}{2}-C(I).$$

To summarise the assumptions are:

1. No change in the resistance of the wire due to the introduction of electrolytic current.
2. Marked effect is due to the change of potential difference due to the variation of point to point current in the wire.

(a) Due to the superimposition of electrolytic current $x/2$ to 0 along the length l_1 and 0 to $-x/2$ along the length l_2.

(b) $l_1 > l_2$

(c) Increase in the leakage of current through the electrolyte will decrease the potential by a factor $C(I)$.

(d) The factor $C(I)$ will increase with the increase of x and may become almost constant after attaining a maximum value. Thus

$$(R+dR)I = RI+\frac{(l_1-l_2)}{2}\rho\frac{x}{2}-C(I);$$

or,
$$dRI = \frac{l_1-l_2}{2}\rho\frac{x}{2}-C(I)$$

Let $(l_1-l_2)=2\Delta l$; [Δl being the distance of the bifurcating point D, from the middle point of the platinum wire.]

Then

$$dRI = \Delta l\frac{\gamma}{L}\frac{x}{2}-C(I),$$ where $\rho=\frac{\gamma}{L}$, L being the length of the platinum wire;

or,
$$\frac{dR}{\gamma}=\frac{\Delta l}{2L}\cdot\frac{x}{I}-C'(I),\ \text{where } C'(I)=\frac{C(I)}{\gamma I}$$

This deduction is very well demonstrated by the graphs drawn between dR and x (see Fig. 3)

when

$$\frac{\Delta l}{2L}\cdot\frac{x}{I}<C'(I),\ dR \text{ is negative;}$$

$$\frac{\Delta l}{2L}\cdot\frac{x}{I}=C'(I),\ dR \text{ is zero;}$$

and when $\frac{\Delta l}{2L}\cdot\frac{x}{I}>C'(I)$, dR is positive.

Δl seems to be the property of the ratio of the potentials of points A and B with respect to the cathode cylinder and hence Δl will go on decreasing and may become nearly constant at higher electrolytic currents when potentials of A and B with respect to the cylinder are large.

The leakage fraction $C'(I)$ increases with the increase of x due to the increase of the conductivity of the electrolyte and attains a maximum value (say at about 100 mA. of electrolytic current) and then becomes almost constant.

This effect is very clearly brought out in the experimental curves (Fig. 3) giving an increase of dip in the negative sector. and as soon as both the factors Δl and $C'(I)$ become constant a straight line portion of the curve is obtained which satisfies the equation

$$\frac{dR}{r}=\frac{\Delta l}{2L}\cdot\frac{x}{I}-C'(I),\ \text{for } dR \text{ and } x.$$

The values of Δl and $C'(I)$ are calculated for different currents from the straight line portions of the curves and are shown in Table I.

TABLE I

Values of $\Delta l/2L$ and $C'(I)$ for different heating currents.

No.	Heating current I in amperes	$\Delta l/2L$	$C'(I)$
1.	0.25	0.009	0.0024
2.	0.75	0.025	0.0038
3.	1.00	0.030	0.0056
4.	1.25	0.035	0.0090
5.	1.50	0.037	0.0116
6.	1.75	0.039	0.0159
7.	2.00	0.041	0.0215

Both the factors $\Delta l/2L$ and $C'(I)$ are found to be increasing with the increase of the heating current I. They do not give any simple relationship with the heating current or electrolytic current which shows that the relations are quite complex.

RESULTS AND CONCLUSIONS

(1) When an electrolytic current is applied on a heated platinum wire through a central tapping O in a shunt resistance there is no change in the resistance of the platinum wire.

(2) The effect is purely a change in the potential across the platinum wire. The change is due to the addition of two factors :

(a) Electrolytic current does not flow on equal portions from the two ends of the platinum wire, resulting in an increase of potential difference proportional to Δl. This factor Δl decreases with the increase of the electrolytic current and then becomes constant.

(b) Decrease of potential difference due to the leakage of current through the electrolyte by a factor $C'(I)$. This factor $C'(I)$ increases with the increase of the electrolytic current and then becomes constant.

(3) The constant values of Δl and $C'(I)$ both are found to be increasing with the increase of the heating current I.

These results, therefore, conclusively go to show that the superimposition of the electrolytic bubble formation causes no decrease and/or increase of the resistance of the platinum wire. Therefore, there is no adequate evidence to show that there is any marked effect of change in the heat transfer from the heated platinum wire as reported by the previous authors (Bhand, Gaur and Gogate, 1963).

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